FOUR YEARS VALIDATION OF A DECISION SUPPORT FOR OPTIMISING HERBICIDE DOSE IN WINTER

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Summary: CPOWeeds is a version of Danish Crop Protection online adjusted to conditions in North-eastern Spain. The predicted efficacies and the yield obtained with CPOWeeds were validated in winter cereal field trials from 2010 to 2013. The predictions from CPOWeeds were compared to the actually achieved efficacies in the field trials for the nine weed species at different developmental stages and for 84.2% of the comparisons the obtained efficacies were equal to or higher than predicted. It was concluded that the use of CPOWeeds allowed optimisation of the herbicide application with a very high robustness. The recommendations were satisfactorily for the conditions of the Northeast of Spain and have the potential to decrease the amount of applied herbicides by at least 30%. Therefore, it can be an important tool in Integrated Weed Management.

Keywords*:* Optimization, herbicide, Decision Support Systems (DSS).

Resumen: ***Validación durante cuatro años de un sistema experto para optimizar el uso de herbicidas en cereales de invierno en condiciones agronómicas españolas***. El CPOWeeds es una versión del Crop Protection Online danés puesto a punto para las condiciones del noreste (NE) de España. Las eficacias predichas por el programa se han validado en ensayos en cereal de invierno desde 2010 a 2013. Las predicciones dadas por el CPOWeeds se han comprobado para nueve especies de malas hierbas en diferentes estadios fenológicos y en el 84,2% de los casos las eficacias han sido iguales o superiores a las predichas. Se concluye que el uso del CPOWeeds permite optimizar la aplicación de herbicidas con una gran robustez. Las recomendaciones son satisfactorias para el NE de España y se puede disminuir la cantidad de herbicidas

aplicados hasta en un 30%. Por tanto, se trata de una herramienta muy importante en el Manejo Integrado de Malas Hierbas.

Palabras clave: Optimización, herbicida, Sistema de Apoyo a la Decisión.

INTRODUCTION

Decision Support Systems (DSS) play an important role in the selection of optimal plant protection products PPP's and dosages. Such systems can specify the relevant herbicides and dosages to reflect the actual weed infestation in a field under actual spraying conditions and thus ensure proper weed control. Even though, these DSS's have good potentials for reducing herbicide use, there are relatively few farmers and advisors using them on Europe. Moreover, farmers prefer high control every year, especially in a crop preceding another in which weed control is more expensive or difficult. Integrated pest management (IPM) is, however, gaining interest and the annex of 2009/128/EU Directive explicitly demands the member states to implement IPM, which imply a decreased reliance on PPPs.

Crop Protection Online (CPO) is a DSS developed and managed by Aarhus University, which was commercialised in 1991 (Rydahl, 2003). CPOWeeds optimises herbicide combinations and dosages in relation to the actual crop and weed infestation either by lowest dose or lowest price. As one herbicide rarely controls all weeds in a field, the model also includes calculation of herbicide mixtures by use of the additive dose model (ADM) (Streibig, 1981). For example, in the current Danish version, it is estimated that herbicides inputs in cereal crops can be reduced by over 40% without enriching soil seedbank for the succeeding crops.

The objectives of this study were to validate the concept of CPO under climatic conditions different from northern Europe with a version of CPO developed for the North-east of Spain. The ability to preserve yield and the robustness of the obtained efficacies were validated. The aim of this work was to examine locally generated parameters and adjustments for the dose-response function described in (Rydahl, 2003) with regard to herbicides and weeds present in winter cereal fields in the North-east of Spain. The prototype was developed under the name CPOWeeds.

MATERIALS AND METHODS

Model description and adjustments made for conditions in the North-east of Spain

CPOWeeds is dependent upon parameterisations of dose-response curves for all relevant combinations of herbicides and weed species. Given the amount of existing herbicides and diversity of weed species it is a huge task to provide data for this amount of dose-response curves. Therefore, different approaches were used to collect the data. Dose-response curves were preferentially estimated based on field experiments.

Target efficacies were established by local expert evaluation. Although, at a practical level, only efficacies between 75 and 95% are recommended, lower efficacies were established for research purposes. CPOWeeds listed all possible solutions for a given weed composition in specific fields sorted by Treatment Frequency Index (TFI). TFI is a measure of the dose reductions, where TFI of 1 equals label rate and lower TFI indicates dose reductions.

Field trials

Two trial setups were conducted from 2010 to 2013. Under the climatic conditions in the region no differences were expected between the weed species composition. The target efficacies required in the different crop types were considered equal.

Field trials were carried out in 2 x 10 or 4 x 5 m plots for efficacy and yield experiments, respectively, with four replicates at each location. For each efficacy trial a number of recommendations from the prototype were tested (Table 1).

The fields were surveyed at 10-11 BBCH of the weeds and a weed report was made to supply data for CPOWeeds. A solution for the early stage was calculated by CPOWeeds and applied at this stage as one treatment. The fields were surveyed again at the 12-14 and at 16 BBCH and again solutions were calculated and applied for each growth stage. A standard treatment was chosen by local advisors for all fields to have a reference for the CPOWeeds solutions.

Herbicides were applied with a precision sprayer propelled by compressed nitrogen. The boom had four Hardi ISO LD-110-02 flat fan 110 degrees opening nozzles operating at a forward speed of 0.9 m s^{-1}, and 300 l ha^{-1} of spray solution. The boom was 50 cm above the target.

Treatment efficacy was assessed 35 days after treatment by four random counts per experimental plot, throwing a square of 0.1 m^2. Yield was estimated harvesting three randomly squares of 0.1 m^2 in each plot.

Table 1. Efficacy and yield trials. TFI for CPO treatment was calculated as an average of the different solutions applied in the fields. Standard TFI was the TFI of the reference treatments selected by local advisors. The reduction in TFI is the difference between the two TFI measures.

Trial purpose	Year	Location	Crop	Weeds found in field	Number of CPOWeeds treatments	Standard TFI	Average CPO TFI	% reduction on TFI
Efficacy	2010	Ballobar	Barley	*Avena sterilis, Lolium rigidum, Diplotaxis erucoides*	10	2	1.41	29.5
Efficacy	2010	Ballobar	Barley	LOLRI, *Anthemis arvensis*	10	1.8	1.11	38.3
Efficacy	2011	Verdú	Barley	LOLRI, *Veronica hedaerifolia*	6	2	1.52	24
Efficacy	2011	Verdú	Barley	*Papaver rhoeas*, LOLRI	6	1	0.71	29
Efficacy	2011	Verdú	Barley	VERHE, PAPRH	6	1.3	1.01	22.3
Efficacy	2011	Verdú	Triticale	VERHE, PAPRH, AVEST	6	2	1.33	33.5
Efficacy	2012	Algerri	Barley	PAPRH, LOLRI, *Malcomia africana*	6	1.7	1.33	21.7
Efficacy	2012	Algerri	Barley	PAPRH, LOLRI, MAMAF	6	1.7	1.33	21.7
Efficacy	2012	Verdú	Triticale	LOLRI, AVEST, PAPRH	6	1.66	1.33	19.8
Efficacy	2012	Penelles	Barley	ANTAR	8	1	0.34	66
Efficacy	2012	Penelles	Barley	LOLRI, AVEST, PAPRH	8	1.66	0.85	48.8
Efficacy/Yield	2013	Vimbodí 1	Wheat	ANTAR, AVEST, LOLRI	5	2	0.95	52
Efficacy/Yield	2013	Vimbodí 2	Wheat	*Galium aparine*, LOLRI, VERHE	6	2	1.09	45.5
Efficacy/yield	2013	Termens	Wheat	*Alopecurus myosuroides*	7	1	0.68	32

Statistical analyses

Abbott method (Abbott, 1925) was used to calculate the efficacy observed in the field trial. In each treatment the efficacies predicted by the prototypes were compared to the efficacies obtained in the field on a species level. Differences between predicted and observed efficacies were analysed using linear mixed models (fixed effects: species, growth stage at application and year; random effects: field and replicate) using R (R Development Core Team, 2013). Model fits were assessed by visual inspection of residual and normal probability plots. Pairwise differences between variables were evaluated using post hoc T-tests with adjustment for multiplicity (Hothorn, 2008).

Analysis of variance (ANOVA) was performed to determine significant differences between the different obtained yields. The Duncan's Multiple

Range Test was used if necessary for separation of means with α=0.05. The analysis was performed for each field.

RESULTS

TFI of the trials ranged between 1 and 2 for the standard treatments and between 0.34 and 1.52 for the average CPOWeeds treatment. This equals herbicide use reductions between 19.8 and 66 % with a weighted average of 36%.

The accuracy of the CPOWeeds predictions was estimated based upon weed counting 35 days after spraying in the efficacy trials. The observed values were equal to or higher than predicted for 84.2% of the samplings. The efficacy values observed in the field are higher than predicted by the model, with a mean difference of 2.35%.

Nine different species were used in the analyses and there were some differences in the accuracy among the species (Figure 1). The average difference between predicted and observed efficacies for *Avena sterilis, Lolium rigidum* and *Papaver rhoeas*, which are key species in this region, showed a difference just above 2%. The largest differences between predicted and observed efficacies were found for *Lolium rigidum* and *Papaver rhoeas* in 2011, but the differences were not consistently positive or negative. Generally, the negative differences for *L. rigidum* were found for plants sprayed at the earliest stage (BBCH 10-13), whereas there was no tendency for *P. rhoeas* for dependence on growth stage.

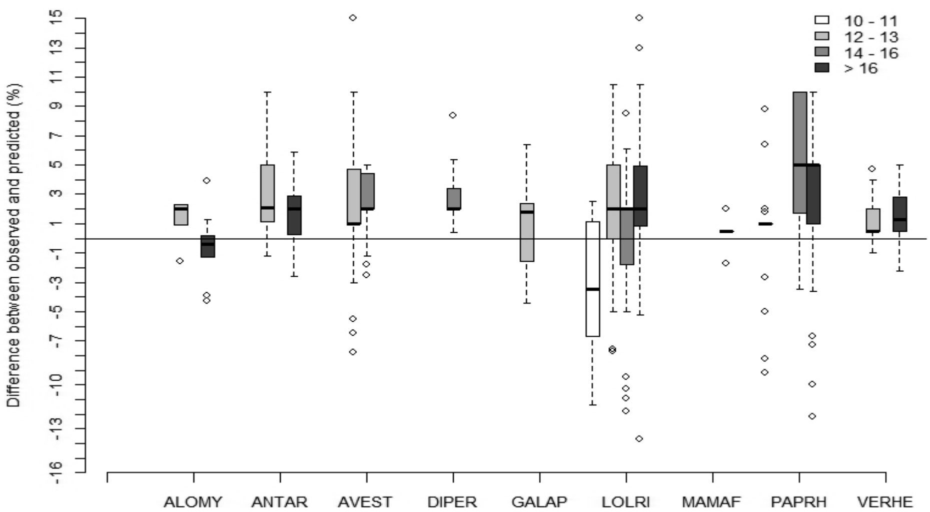

Figure 1. Difference between observed and predicted values for the different species and growth stages (legend indicate growth stages in BBCH scale).

The growth stage of the weed plants at the time of application did not influence the robustness of the model recommendations, as the difference between predicted and observed efficacies did not differ among growth stage ($p = 0.4151$, $n= 4$). The model was designed to account for the developmental stage at the time of application and CPOWeeds was observed to adequately adjust the doses. There was some variation in the magnitude of the difference between predicted and observed efficacies among years ($p = 0.0116$, $n = 4$). The observed efficacies were less consistent with the predicted efficacies in 2011 than in the other three years ($0.0001 < p < 0.0288$ for pairwise comparisons). During that year, the rainfall was only 33.7mm in compared to an average rainfall slightly above 110mm in the period when the field tests were carried out (December 2010 to February 2011).

The yield trials support the results obtained in the efficacy trials, which shows that CPOWeeds provide robust advice that sufficiently control the weeds present in the validation trials (Table 2). The yield of CPOWeeds treatment was equal to or even higher than the standard treatments. At "Termens" there were two CPOWeeds treatments that did not provide the same yield as the standard treatment. This was due to the presence of a resistant *A. myosuroides* population, which was unidentified at the establishment of the trial.

Table 2. Yield trials. Yields of CPOWeeds treatments are given as an interval as 4-6 different solutions were tested in each field. Lower case letters indicate differences between standard treatment and CPOWeeds treatments.

Location	Treatment	Yield (kg ha^{-1})
Termens	Standard	10450[a]
	CPOWeeds	6403[b] – 11006[a]
Vimbodí 1	Standard	4082[a]
	CPOWeeds	4168[a] – 4793[a]
Vimbodí 2	Standard	4763 [a]
	CPOWeeds	6286[b] – 7103[b]

DISCUSSION

In 9 of 17 trials the herbicide reduction obtained was above 30% when the standard treatment was compared to the average TFI of the CPOWeeds treatment. The yield trials supported the general impression from the efficacy trials that no yield loss was induced by following

CPOWeeds recommendations. In some instances there was an increase in yield compared to standard advice.

The obtained results were accurate, with most of the values in the range 0-5% regardless of conditions, weed composition and phenological stages. There were, however, small differences between the growth stages indicating that the model performance was best between stage 12 and 16. Moreover, the herbicides with the highest root activity, is often applied before the actual weed composition can be determined and the application in stage 10-11 might be later than optimal for those herbicides. The standard treatments, decided by the local advisors, in early stages also had lower effect that expected, the data is, however, not shown. Species like *Avena sterilis, Papaver rhoeas* and *Lolium rigidum* are important species in winter cereals in the North-east of Spain and CPOWeeds recommendations provided sufficiently control of these species.

The validation trials showed that CPOWeeds gave robust advice, which sufficiently controlled the present weed species and maintained yields. There were a few fields with inadequate weed control, which were attributed to the lack of identification of a resistant *A. myosuroides* biotype. CPOWeeds are able to handle the identified resistant biotypes. Currently, a resistance prevention initiative is being developed in CPOWeeds, which aims at limiting the development of more resistant weed species by altering the mode of action of herbicides between weed generations.

In the future feedback from users will be important to adjust the target efficacies to levels that will provide sufficient control in all situations. The present target efficacies were estimated by experts, but experiences from Denmark has shown that adjustments are necessary through the initial implementation period as it is difficult to account for all factors. The final conclusion is that the use of this tool allowed an optimising of the application of herbicides, adjusting the applied herbicide rates with a very high robustness, its recommendations were very satisfactory for the conditions of the North-east of Spain and has a potential to decrease the amount of applied herbicides with more than 30%. This, potentially, makes CPOWeeds an important tool in Integrated Weed Management which is faced with the Directive 2009/128/EC in 2014.

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